



Links between Aircraft Emissions and Contrail/Cirrus Properties

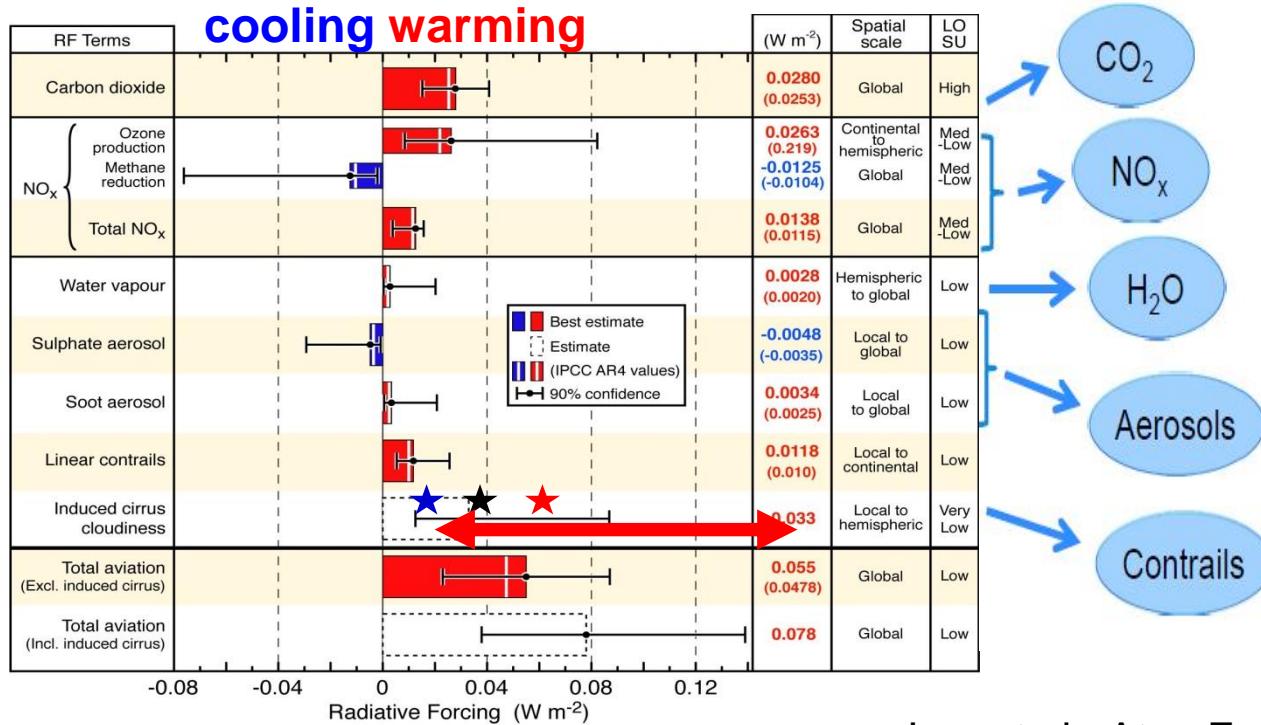
Christiane Voigt, Tina Jurkat, Romy Schlage, Stefan Kaufmann, Hans Schlager, DLR
Bruce Anderson, Rich Moore, NASA



Why contrails?

Contrails have the largest contribution to the total aviation effect on climate (> CO₂)

Radiative forcing RF from aviation in 2005; $\Delta T_{\text{surf}} = \lambda \cdot \text{RF}$

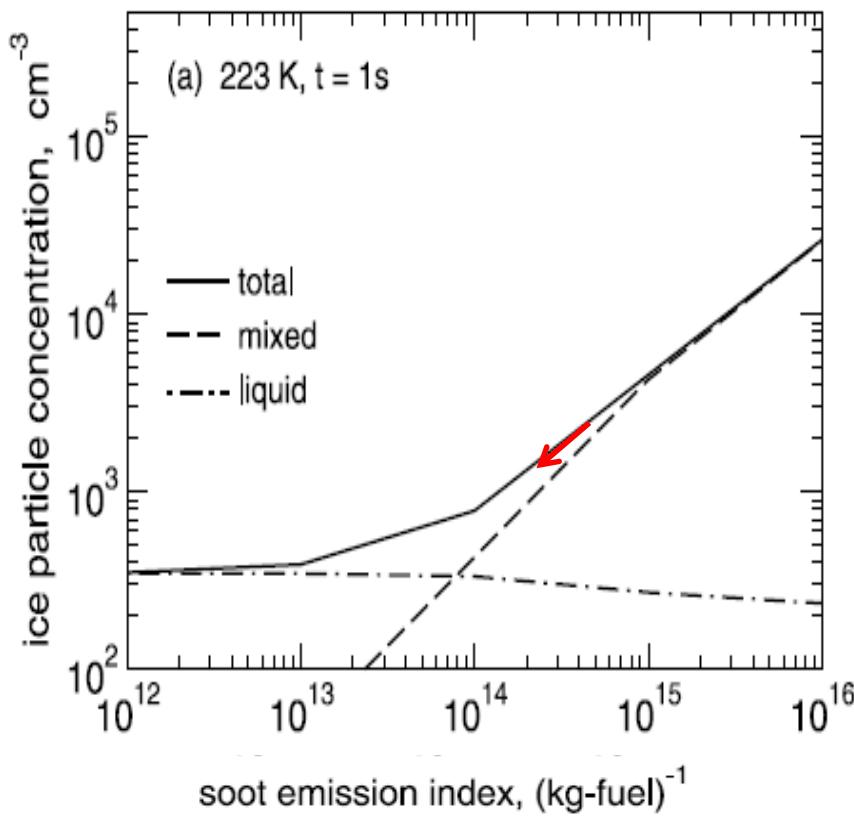


Lee et al., Atm. Env, 2009

New studies on contrail cirrus :

Chen & Gettelman, 2013, Burkhardt & Kärcher, 2011, Schumann & Graf, 2013
IPCC 2013 recommended value for contrail cirrus RF 0.05 (0.02 to 0.15) W/m²

Link Aerosol Emissions - Contrail Formation



Kärcher and Yu, GRL, 2011



Scope

- Show results on the particle size distribution in contrails & ambient parameters (T, RHI)
- Compare to previous contrail observations
- Study the temporal evolution of the contrails
- Investigate effects of alternative fuels on contrail properties
 - Particle size distribution in contrails which nucleated on HEFA blends versus JET-A
 - Contrail ice particle number density HEFA - JET-A
 - Derive AEI_{ice} for HEFA - JET-A
 - Relate AEI_{ice} to EI_{soot}
- Outlook, research needs, future studies

DC8



F 20E

CAS-POL - Cloud and Aerosol Spectrometer FSSP300 Forward scattering Spectrometer Probe

Method

- CAS - Particle size distribution (0.61 - 50 µm, 30 size bins) using forward-scattering (4°-12°) of laser beam (685 nm)
- FSSP - Particle size distribution (0.31 - 20 µm, 30 size bins) using forward-scattering (4°-12°) of laser beam (632 nm)
- T, p, particle air speed



Hygrometers

CR-2 - Gas phase H₂O

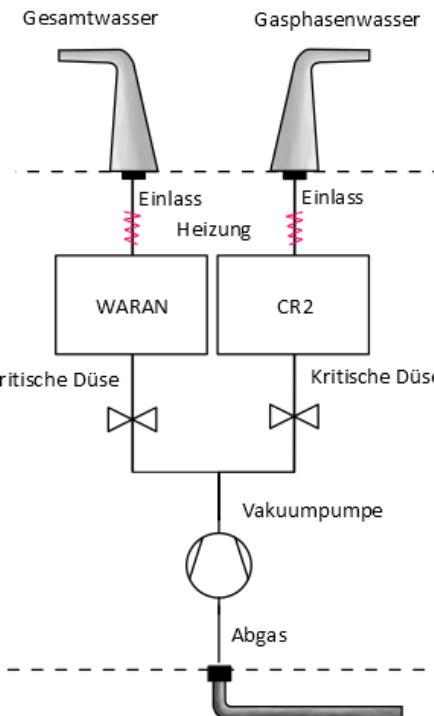
- Dew Point Mirror
- with T from Falcon → RHi



Flugrichtung
←

WARAN (WVSS-II) - Total H₂O

- Tunable Diode Laser Instrument (1,37μm)
- forward facing inlet - Total H₂O

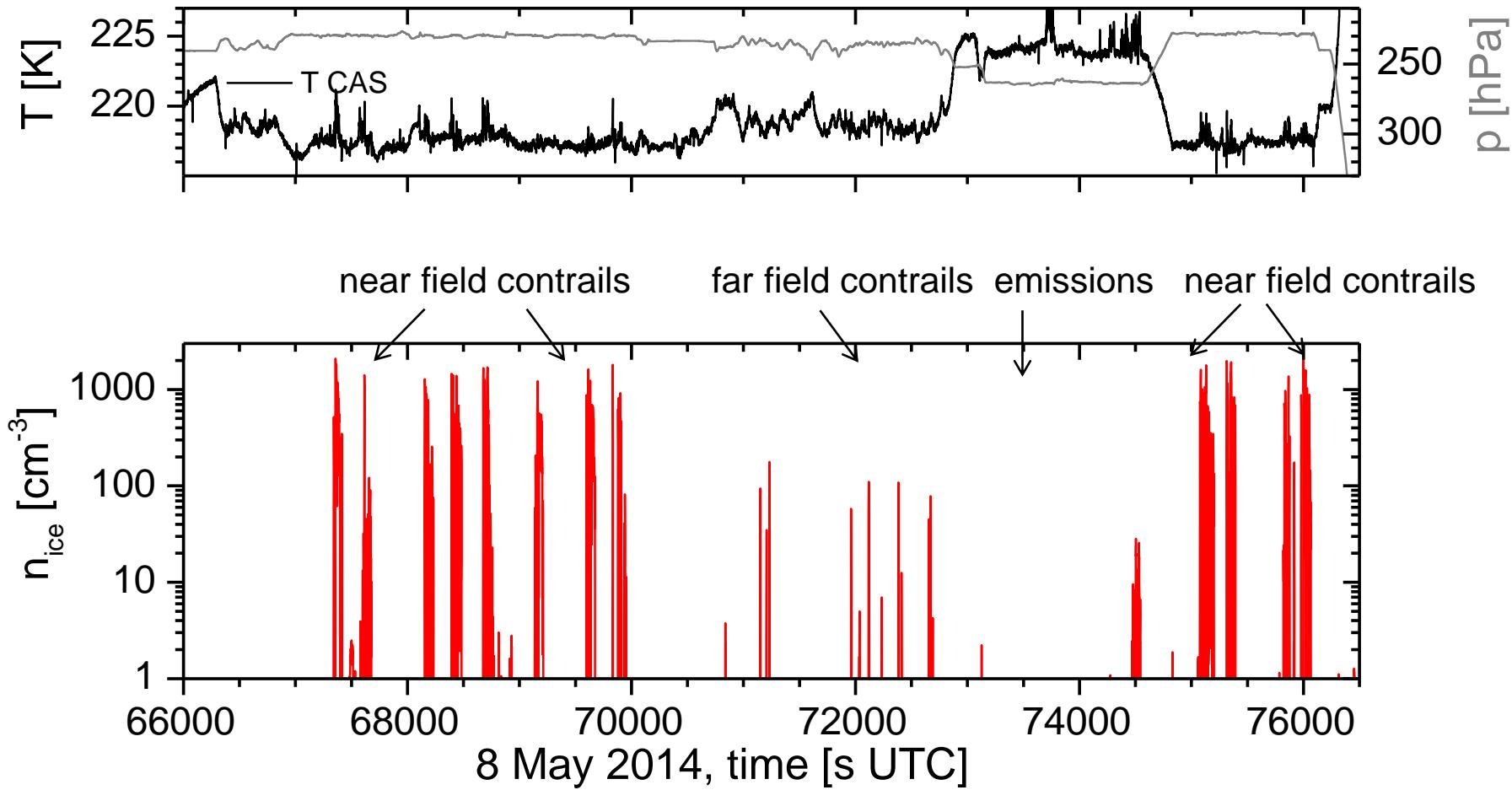


Ice Water Content (IWC)

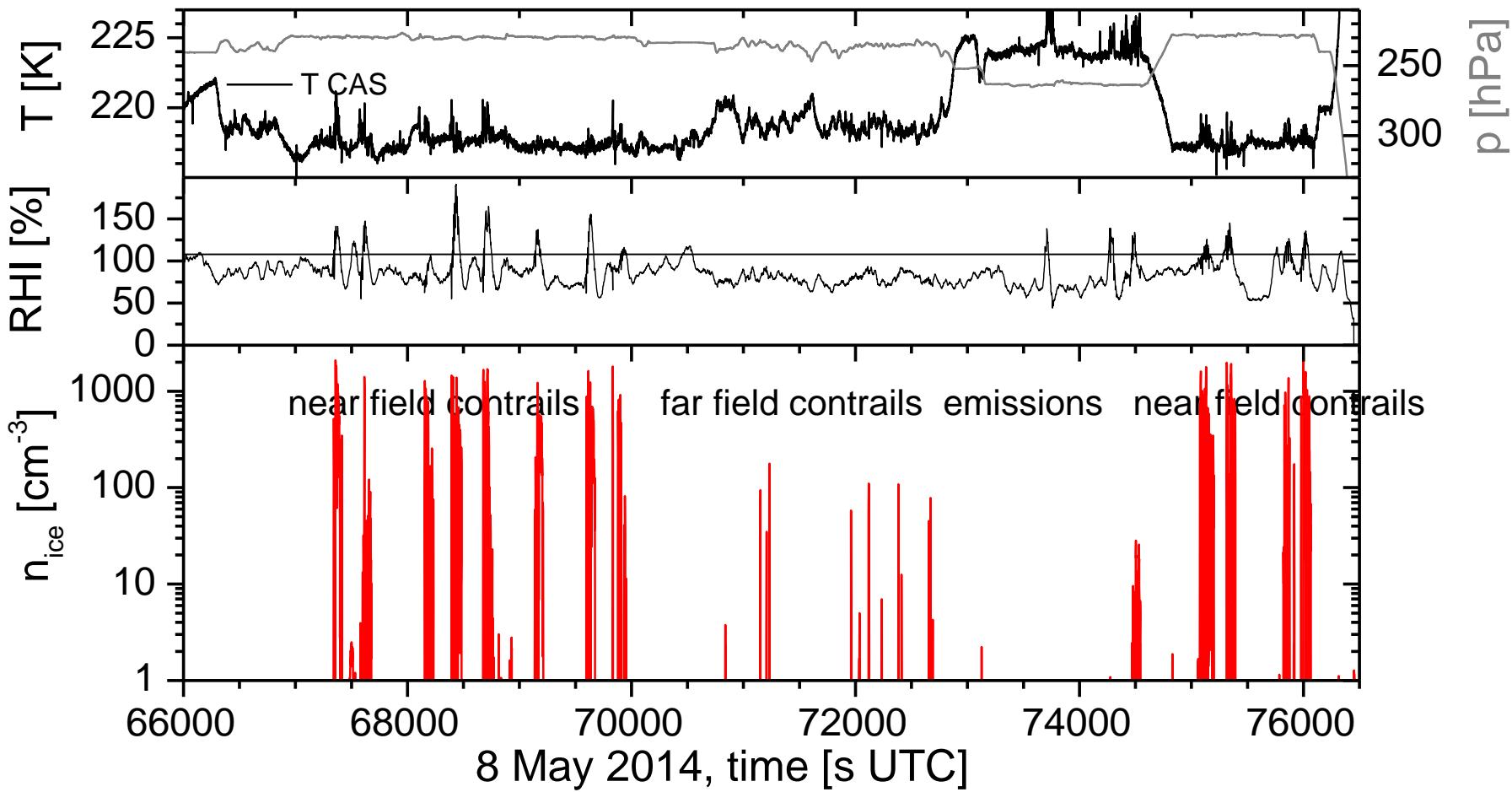
- $(H_2O_{tot} - H_2O_{gas}) / EF$
- Integral over particle size distribution from CAS
- Start with data from 8 May 2014



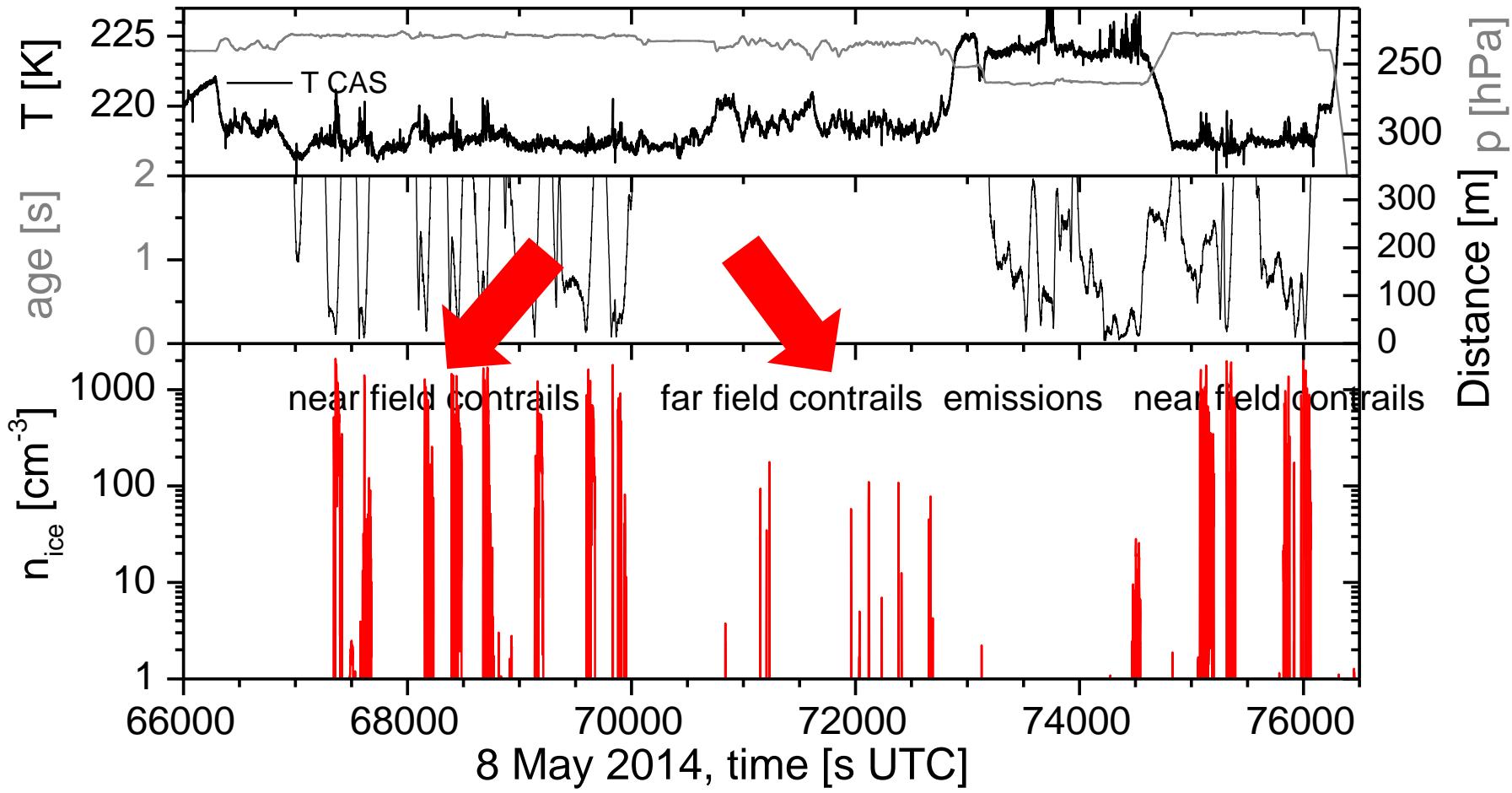
Contrail observations during ACCESSII - 8 May 2014



ACCESSII 8 May 2014 - RHI



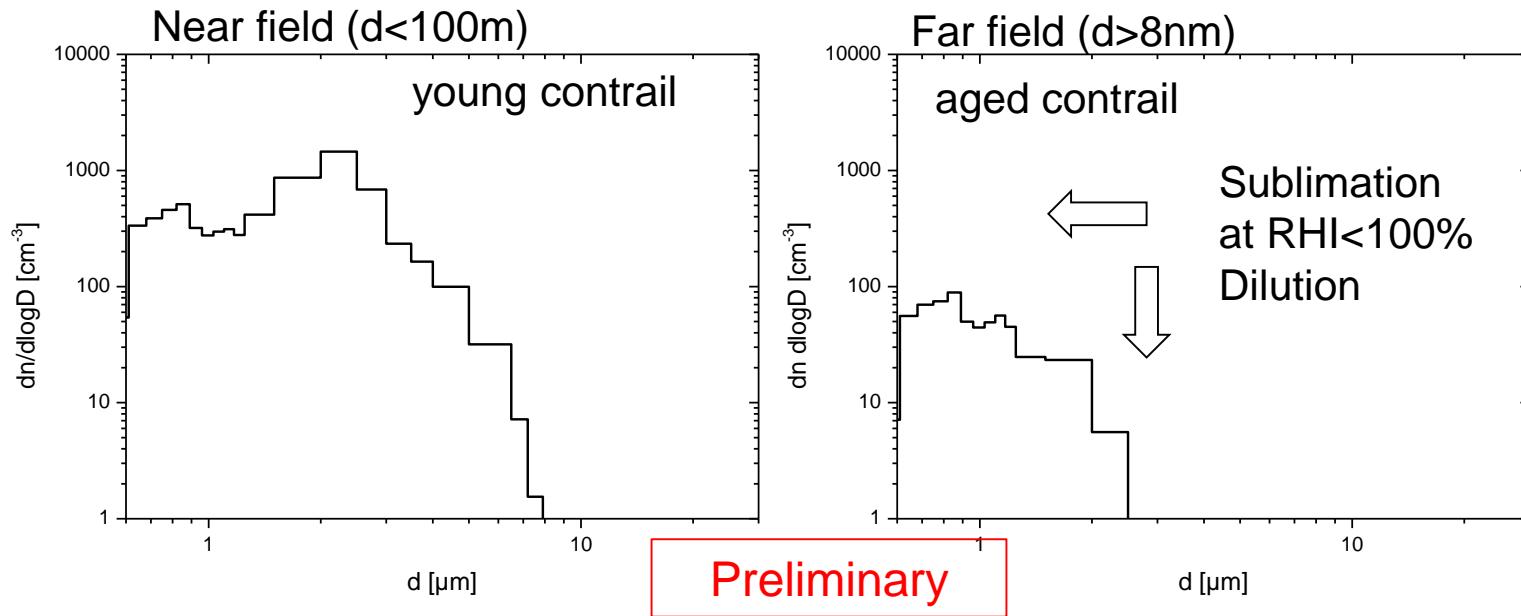
Aircraft distance and contrail age - ACCESSII 8 May 2014



- Age < 1.3s
- Distance >30 m



Contrail size distribution and contrail evolution



- Maximum of particle size distribution near $2.2 \mu\text{m}$ in young contrail (JET-A)
- **Observations in aged contrails required to investigate their climate impact**



Few previous contrail observations at 1 sec contrail age

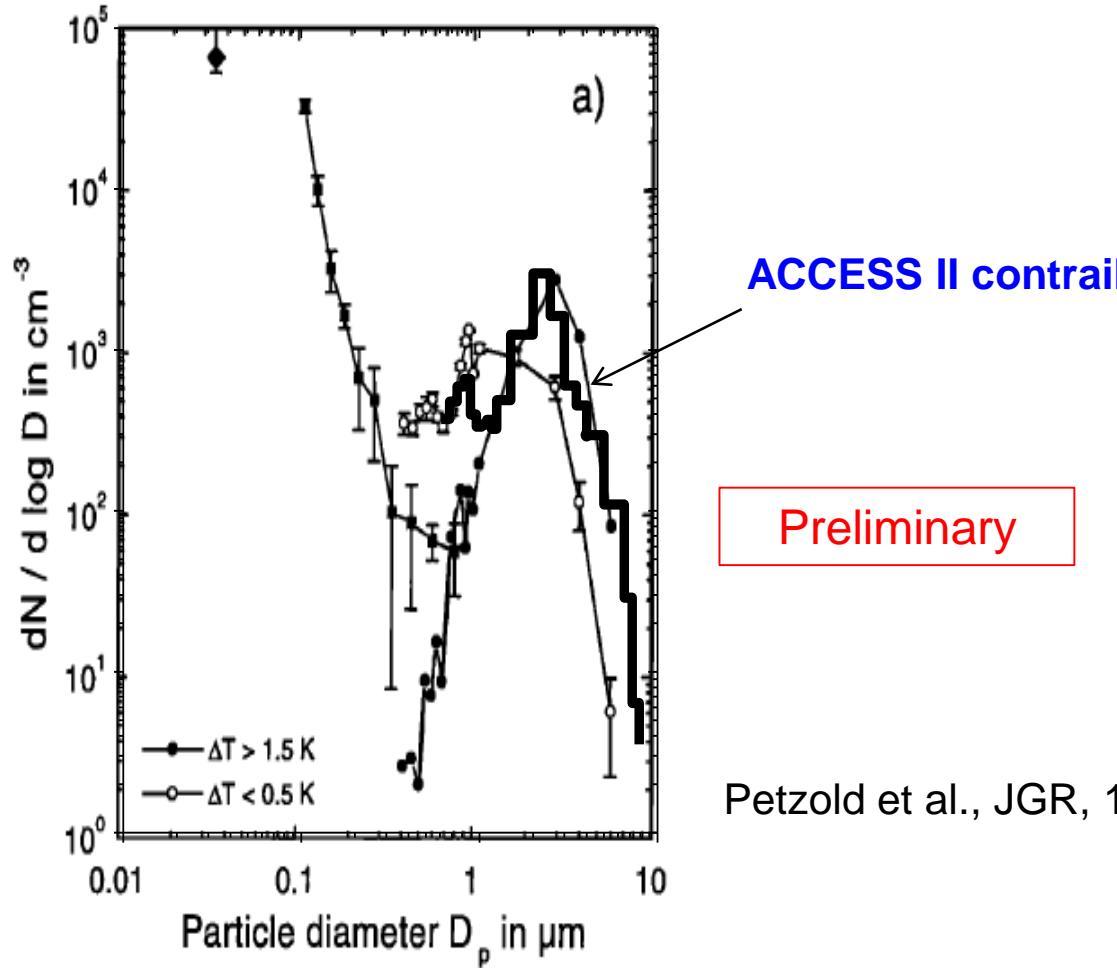
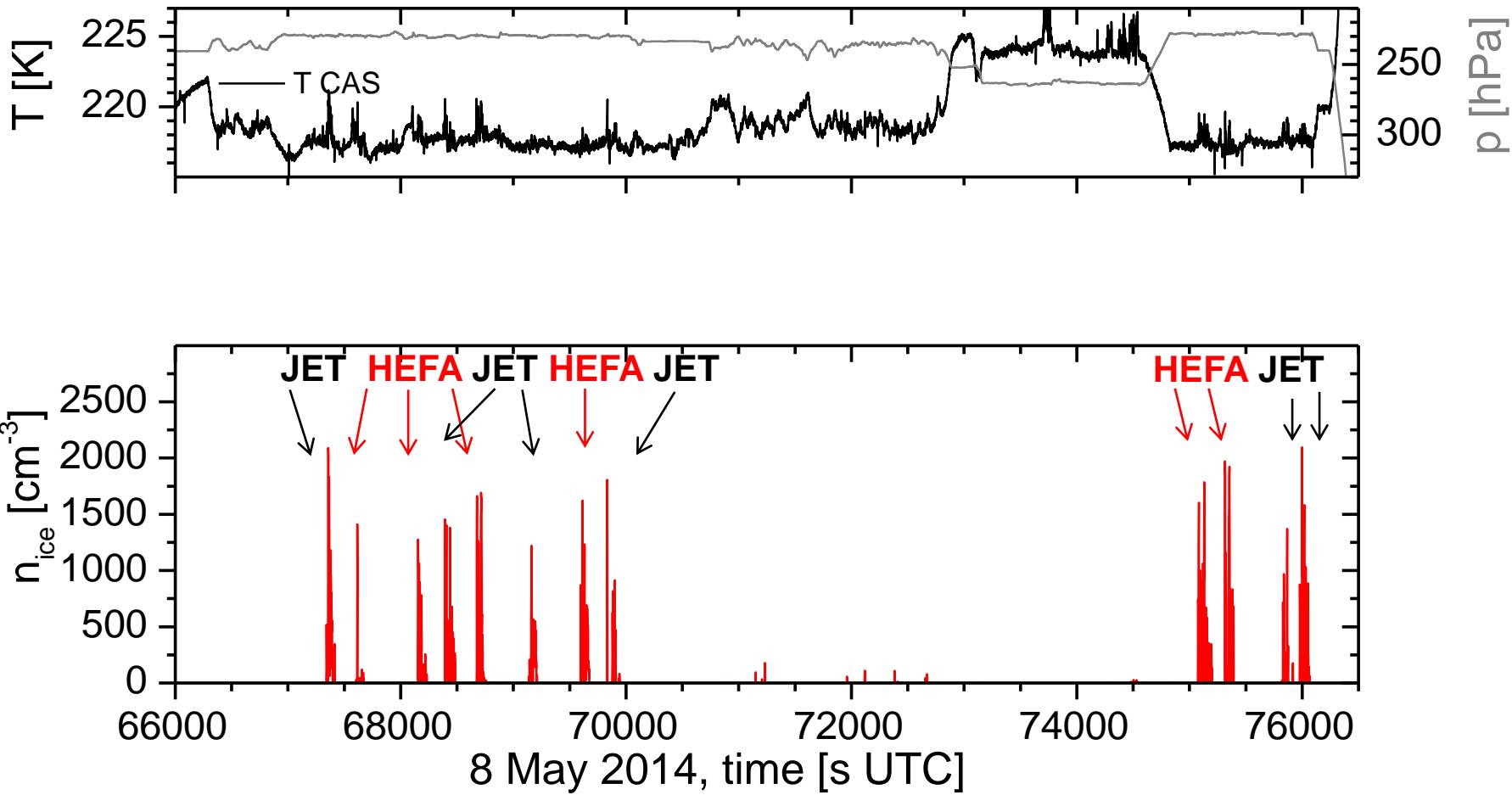


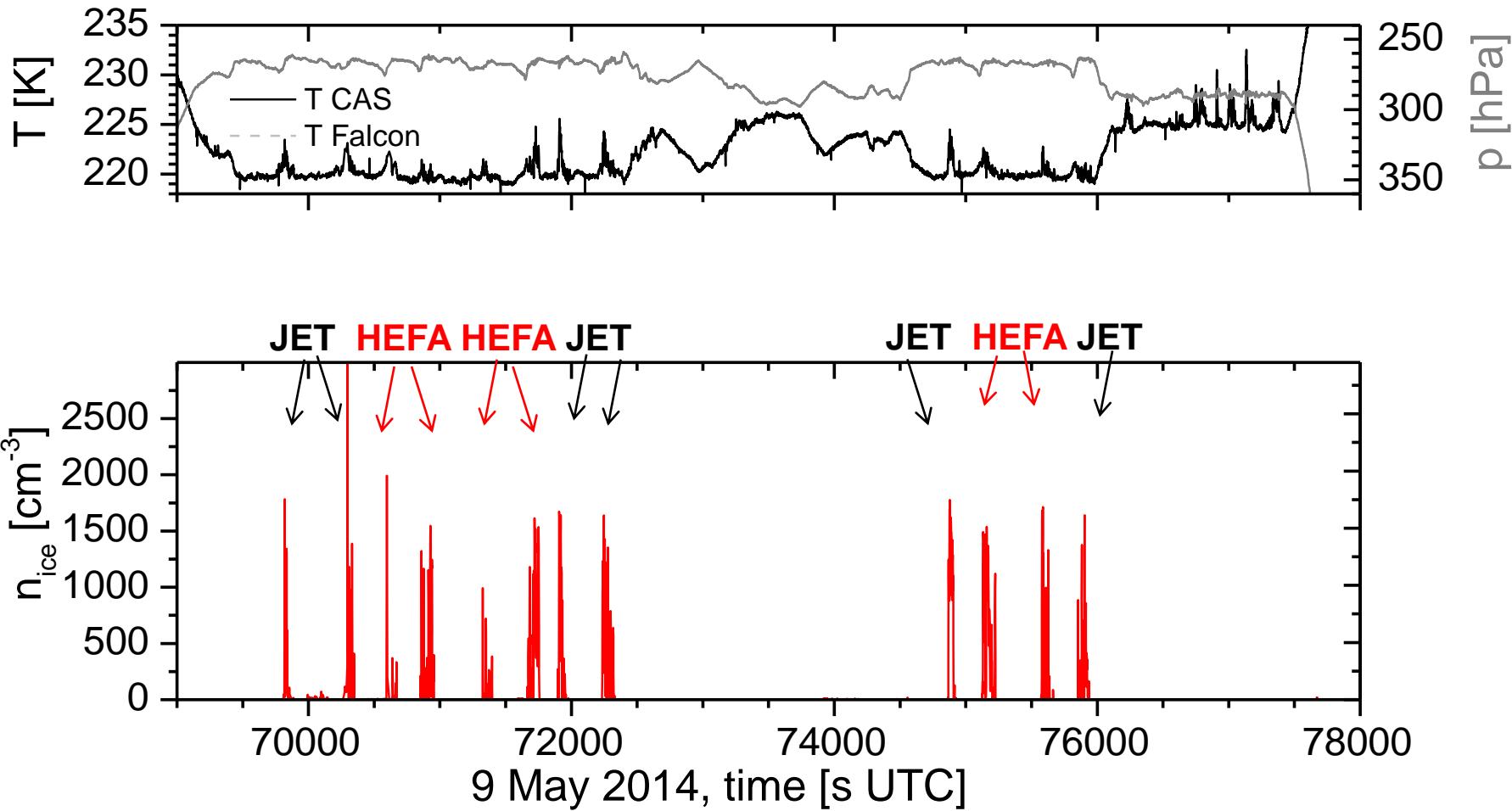
Figure 5. Size distribution of the dry accumulation mode (PCASP-100X: squares) and the contrail particles (FSSP-300: circles) inside the ATTAS contrail (FL 310 on March 15, 1996): short distance ($d \leq 250 \text{ m}$, plume age $< 2 \text{ s}$) with (a) sulfur content 6 ppm and (b) sulfur content $> 2700 \text{ ppm}$; medium



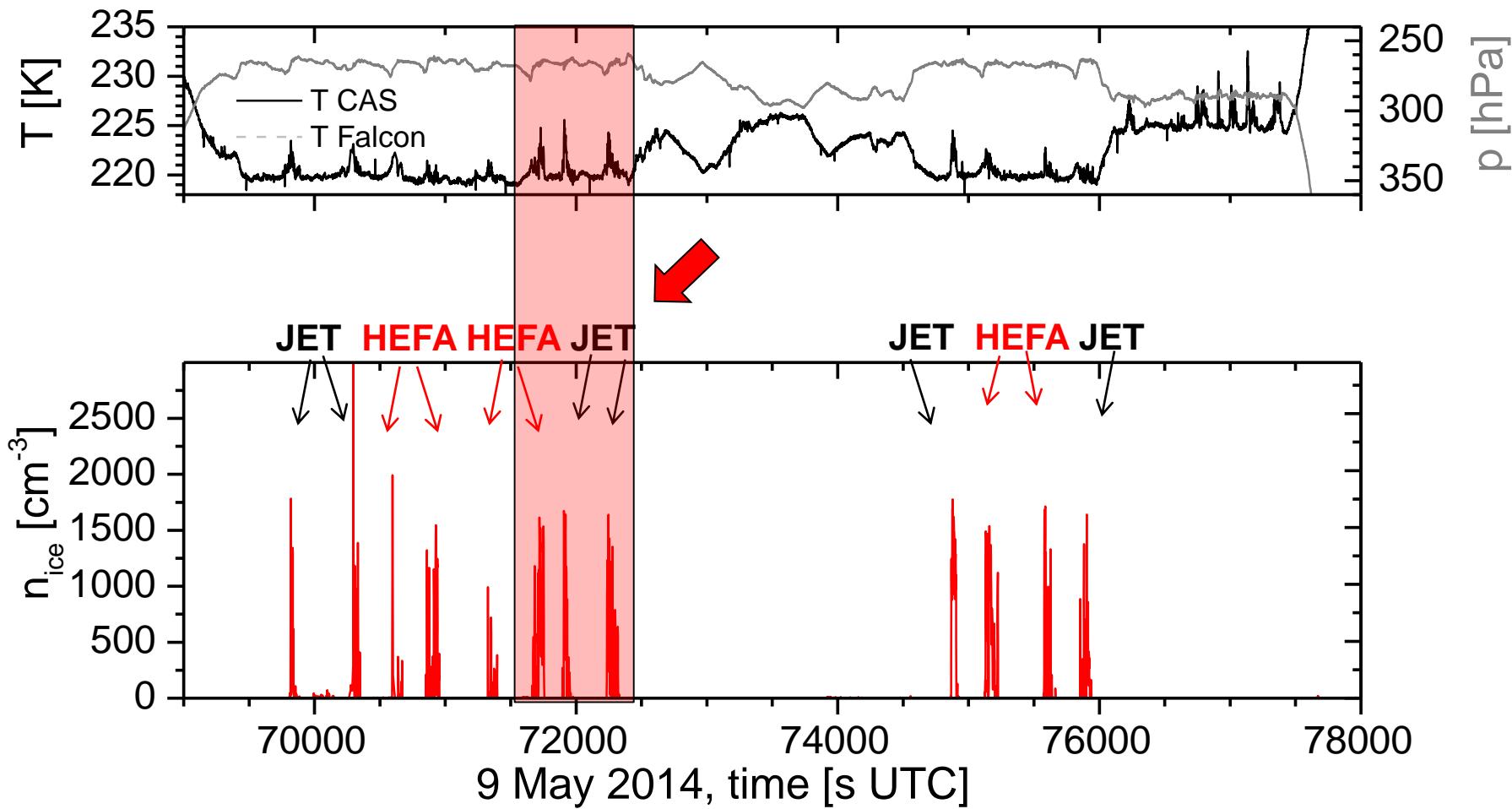
HEFA versus JET-A - ACCESSII 8 May 2014



HEFA versus JET-A - ACCESSII 9 May 2014

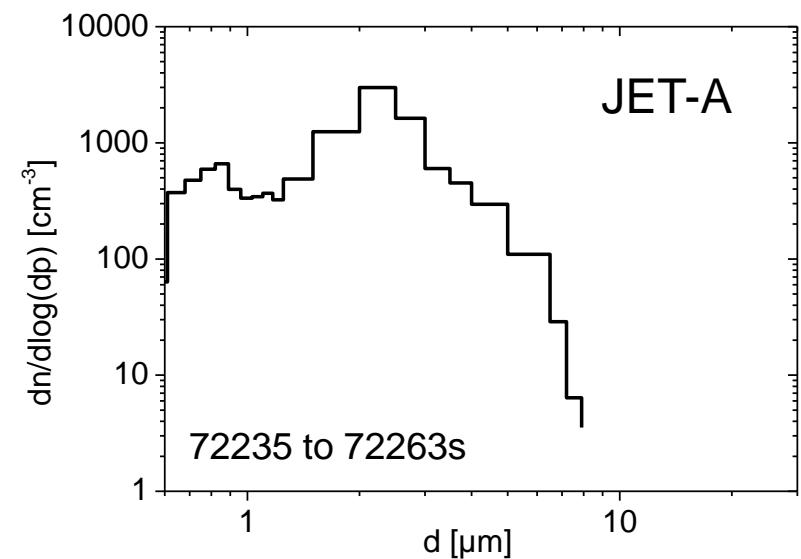
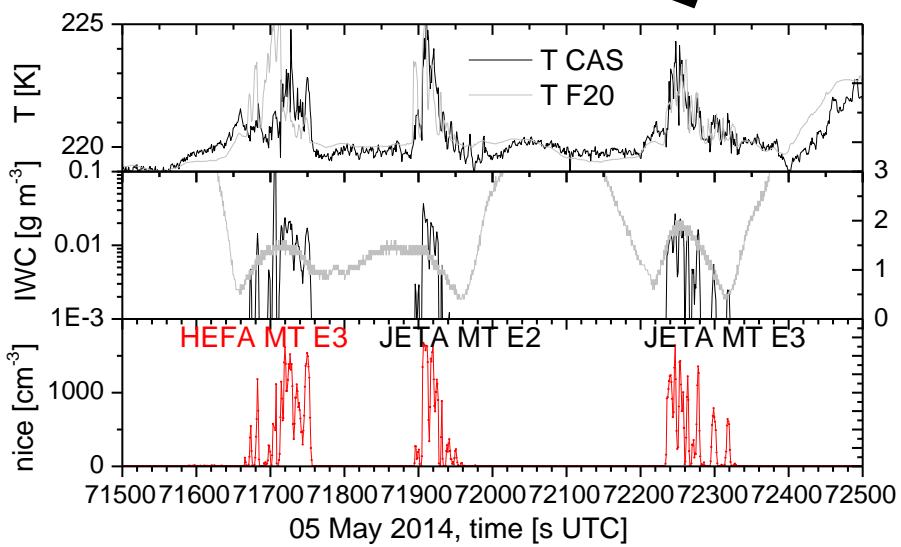


HEFA versus JET-A - ACCESSII 9 May 2014



HEFA versus JET-A - ACCESSII 9 May 2014

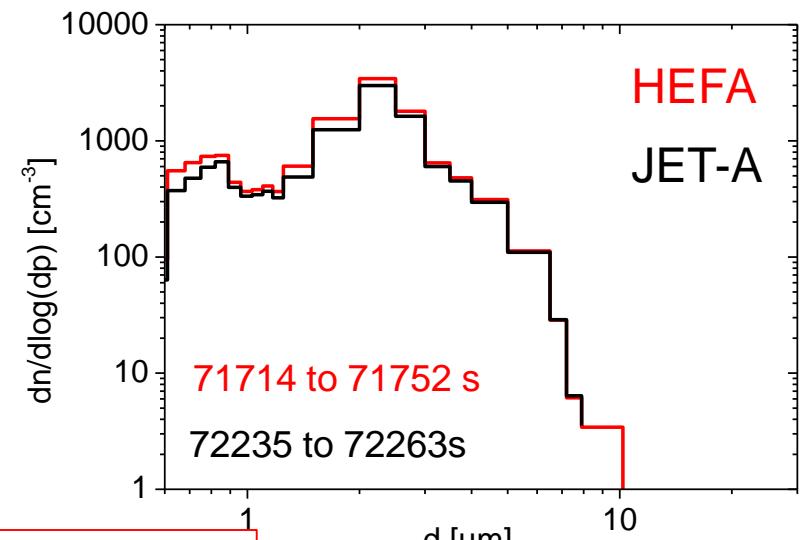
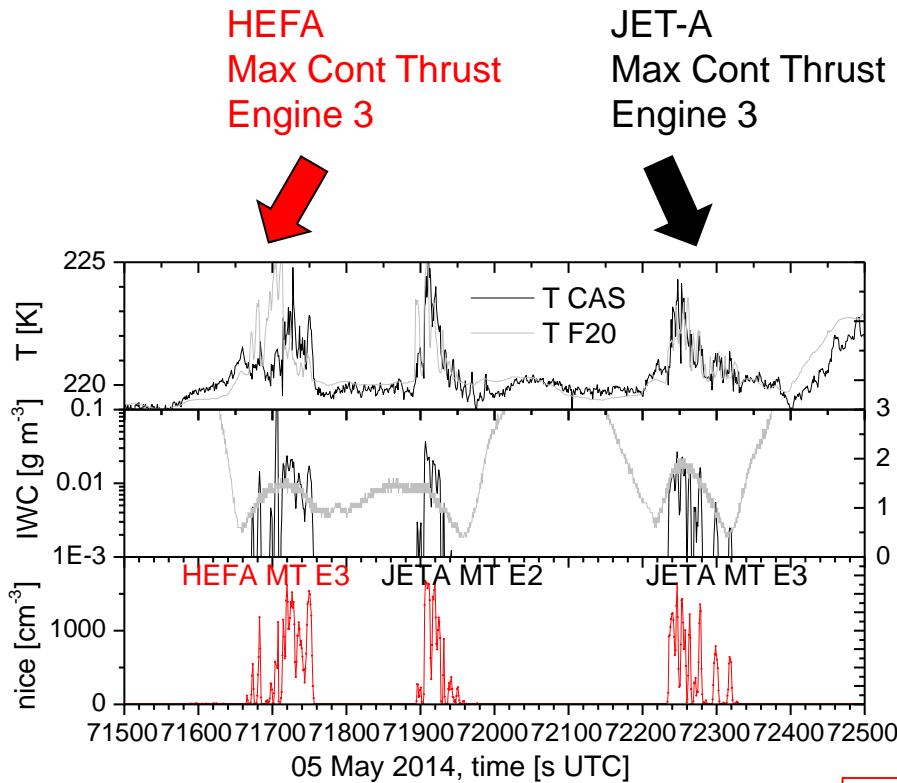
JET-A
max cont thrust
Engine 3



Preliminary



HEFA versus JET-A - ACCESSII 9 May 2014

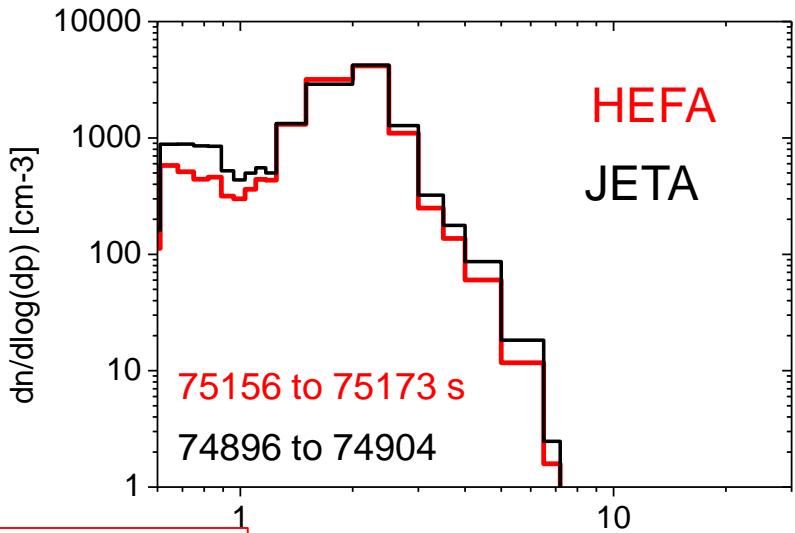
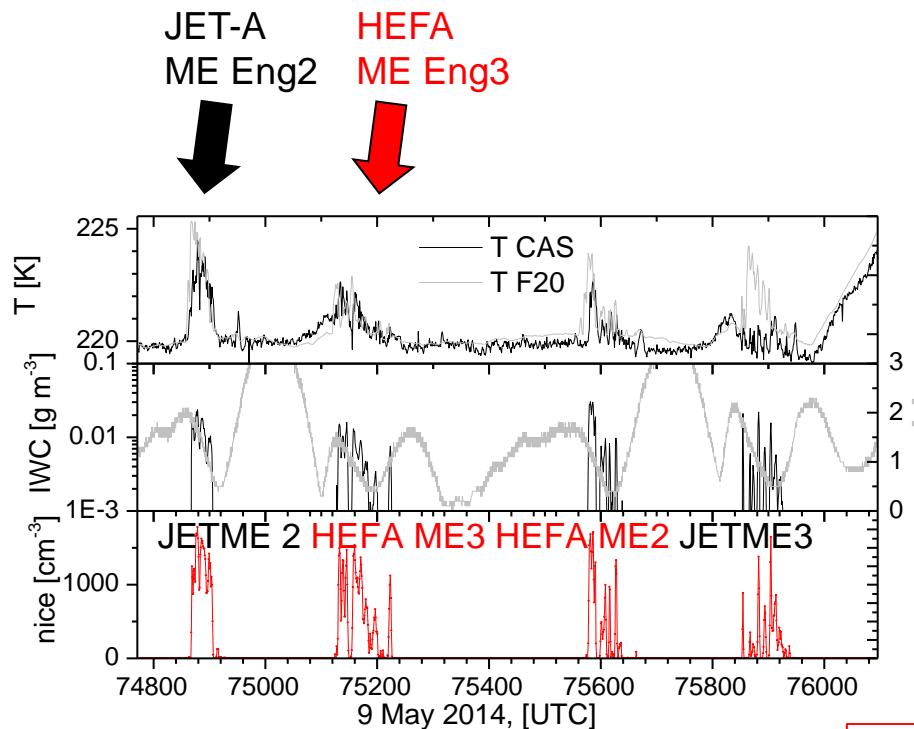


Preliminary

- Similar maximum of the particle size distribution
- Differences in the large and small tail of the PSC



JET-A versus HEFA - ACCESSII 9 May 2014



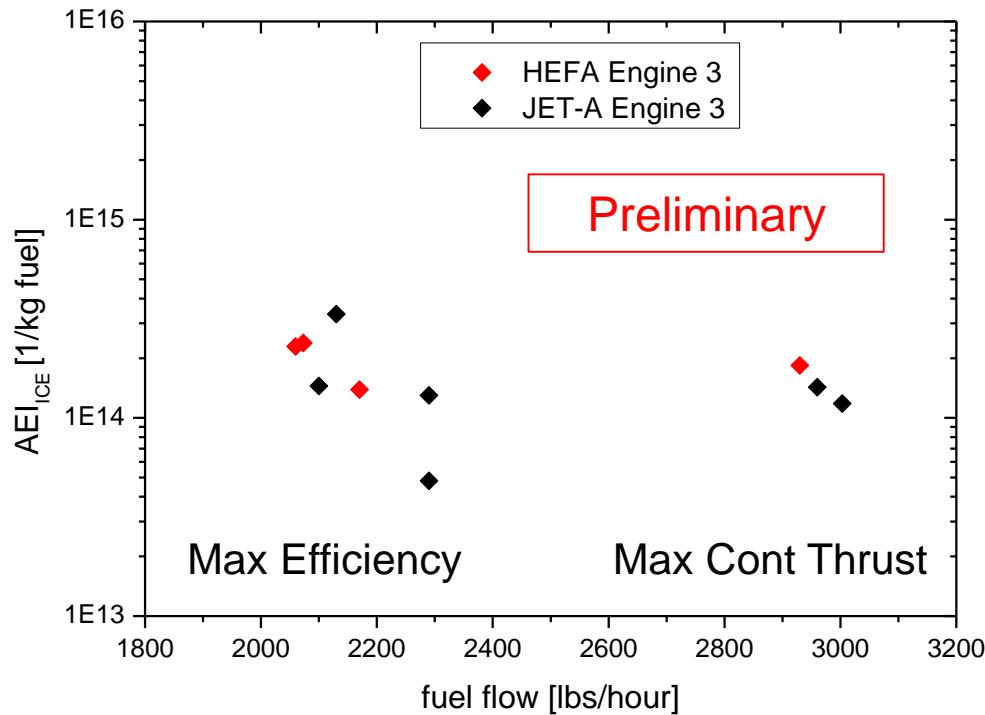
Preliminary

- Similar maximum of the particle size distribution
- Differences in the large and small tail of the PSC



Apparent Emission Index of Ice AEI_{ICE}

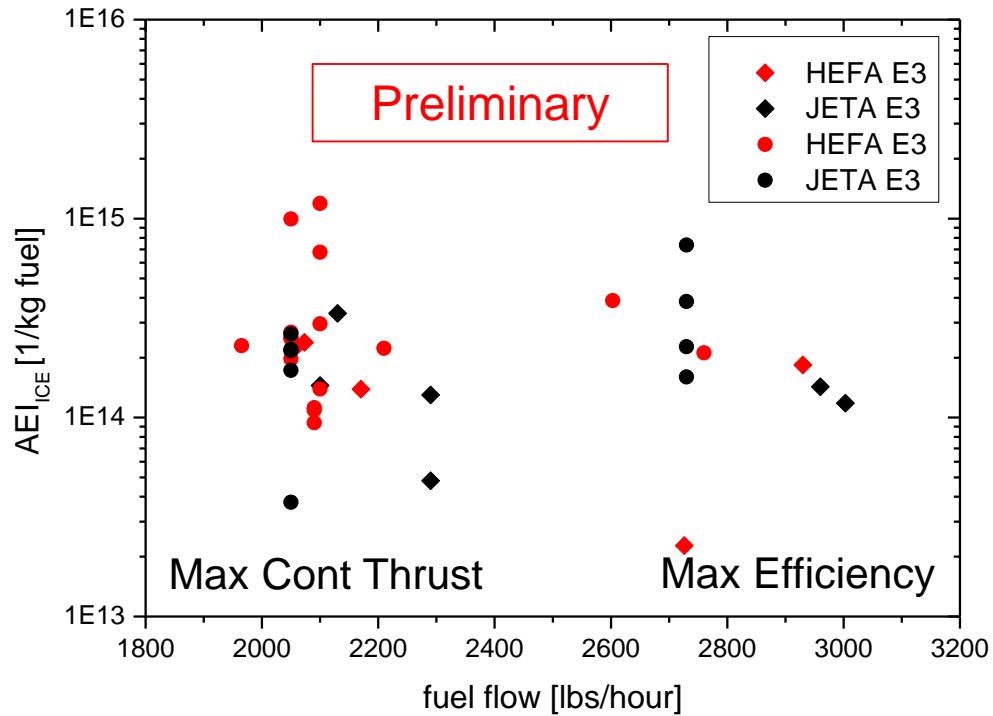
- Coincidence correction after Lance, JAOT, 2012 for CAS
- Use ΔCO_2 or derive $\Delta T - \Delta \text{CO}_2$ relation: $\Delta \text{CO}_2 = \Delta T / 18 \text{ ppm/mK}$
- Calculate AEI_{ICE} after Anderson et al., GRL, 1999
- Integrate over individual contrails, error analysis



Preliminary data



AEI_{ICE} - Data from CAS and FSSP - Engine 3

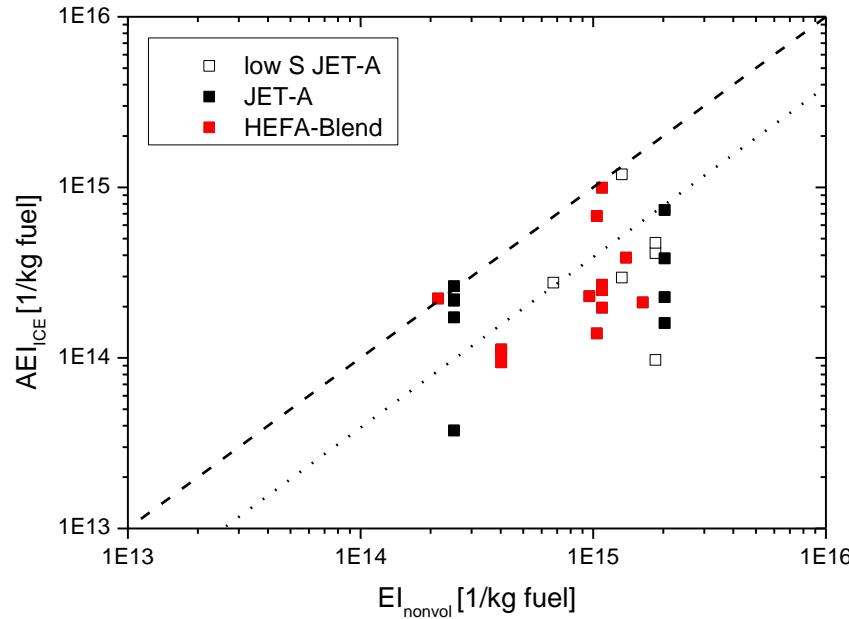


Preliminary data



AEI_{ICE} versus $\text{EI}_{\text{nonvol10}}$

Preliminary

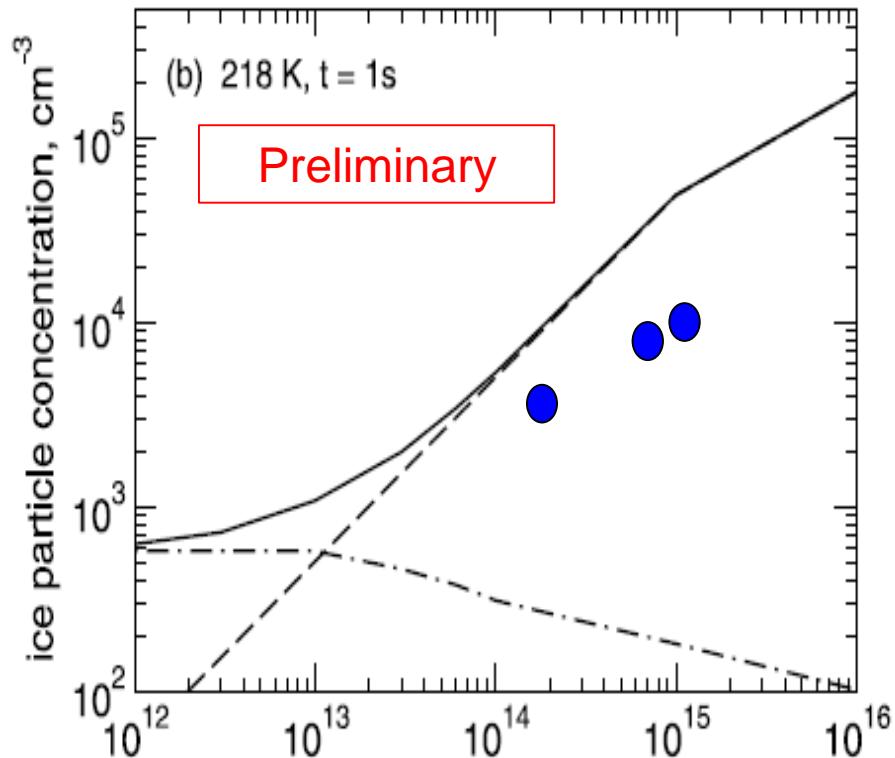
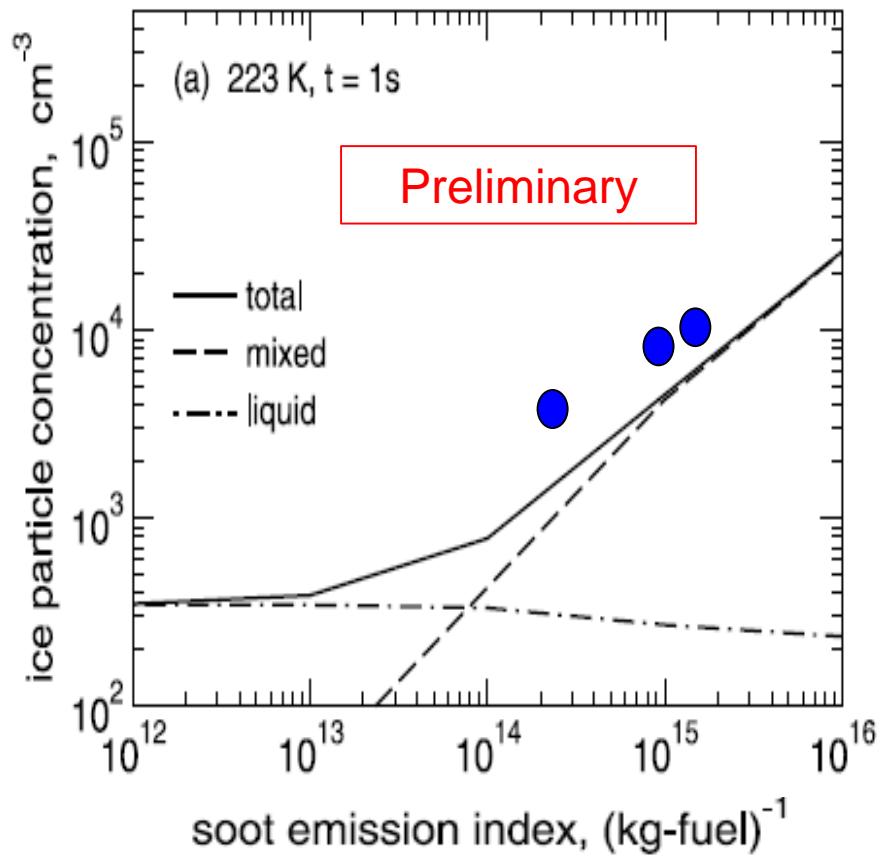


- Large variability
- Higher AEI_{ICE} with increasing $\text{EI}_{\text{nonvol}}$ (soot emissions)
 - indications of an effect of biofuels on contrails
- 10 to 100 % activation of non-volatile emissions (average 39% from FSSP)

Preliminary data



Ice number density versus $EI_{\text{non vol}}$



Preliminary data



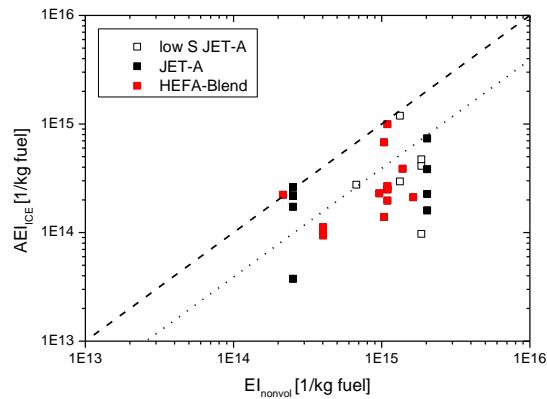
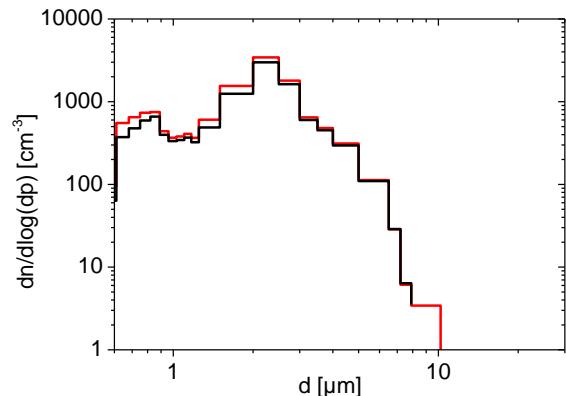
Summary and Discussion

First quantitative detection of contrail properties of bio-fuels in near field during ACCESSI and II

- Age 0.3 to 1.3 s, distance 30 to 250 m
- Ice crystal size distribution peaks near 2 μm in 0.7 s old contrails
- High natural variability in contrail properties and AEI_{ice}

Effects of HEFA blends

- Increase in AEI_{ice} with increasing $\text{EI}_{\text{nonvol}}$ (CAS & FSSP)
- Smaller ice sizes with increasing soot emissions (CDP)
- 10 to 100 (on average 39%) activation of soot particles using FSSP data, lower activated soot fraction from CAS data



Preliminary data



Outlook and Future Work

- Ongoing data analysis
 - Derive uncertainties / investigate natural variability
 - Flight strategy and instrumentation can be optimized
-
- Due to large variability, more observations in young contrails are needed
 - Observation of persistent contrails nucleating on biofuels are missing at all – required to investigate climate impact
 - Observations of contrails on other alternative fuels (e.g. synthetic fuels)



THIS IS NOT THE END



ML - CIRRUS with HALO

- ✓ 24 March – 16 April 2014 from Germany

coordinated by C.Voigt, A. Minikin, U. Schumann, DLR

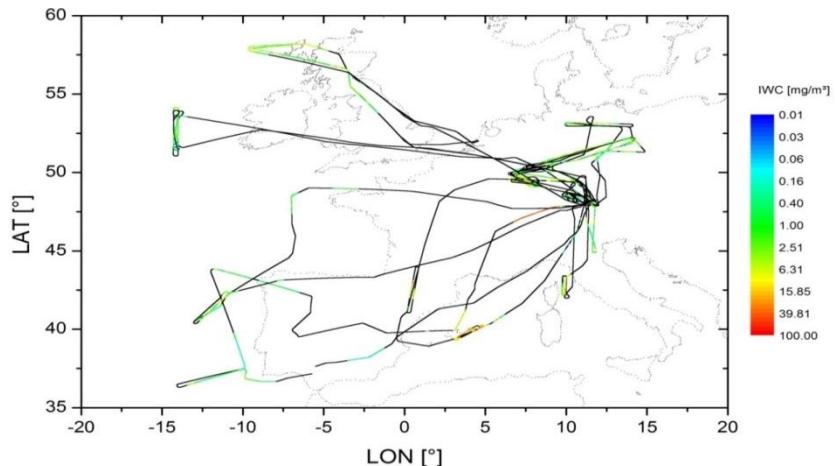
- ✓ ~100 Participants from 12 Institutions

DLR IPA & FX, Research Center Jülich, Karlsruhe Institute of Technology, Universities Mainz, Frankfurt, Leipzig, Heidelberg, LMU München, Max-Planck Institute for Chemistry, Leibniz Institute for Tropospheric Research, PTB, Eidgenössische Technische Hochschule Zürich, CH

- ✓ Focus mid-latitude cirrus and contrail cirrus

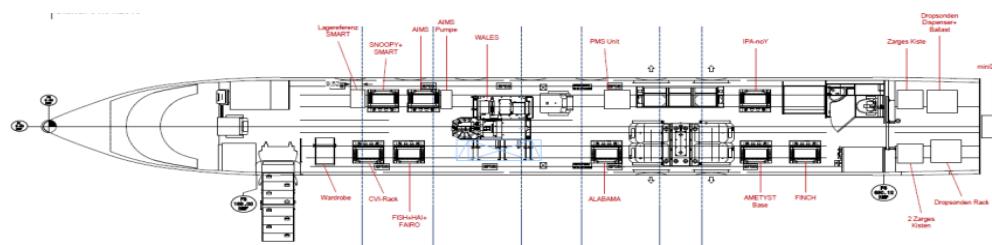
- ✓ 16 mission flights, 88 flight hours

- ✓ 22 h direct cirrus and contrail cirrus observations at typical mid-latitude conditions

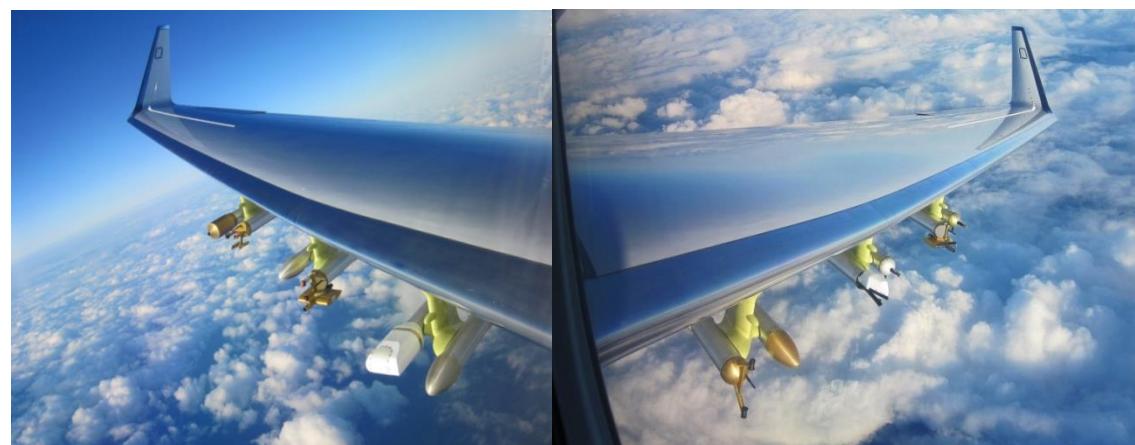
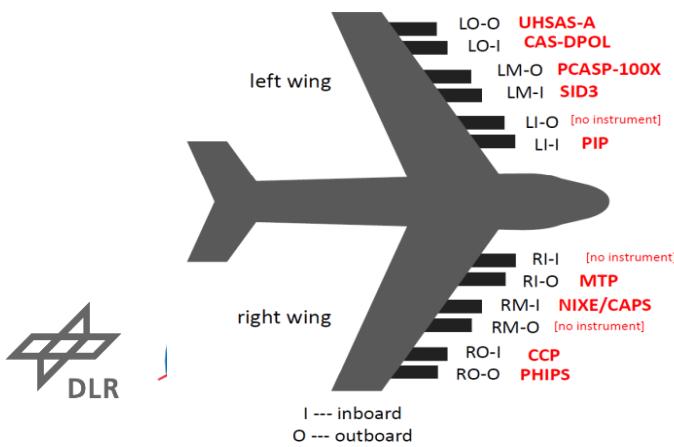


ML-CIRRUS Scope

- Investigate natural cirrus and contrail cirrus to better quantify their climate impact
- Observe microphysical/radiative properties of cirrus and contrail cirrus during their life cycle
- Link dynamics/meteorology and cloud microphysics, life cycle and climate impact
- New research aircraft HALO with novel „State-of-the-Art“ instrumentation
 - 8 cloud probes, aerosol and ice nuclei instrumentation, radiation,
 - 6 hygrometers, dropsondes, trace gas instruments,
 - LIDAR



- Satellite- and model evaluation (MSG, CALIPSO, CoCiP, CLAMS, ETH)

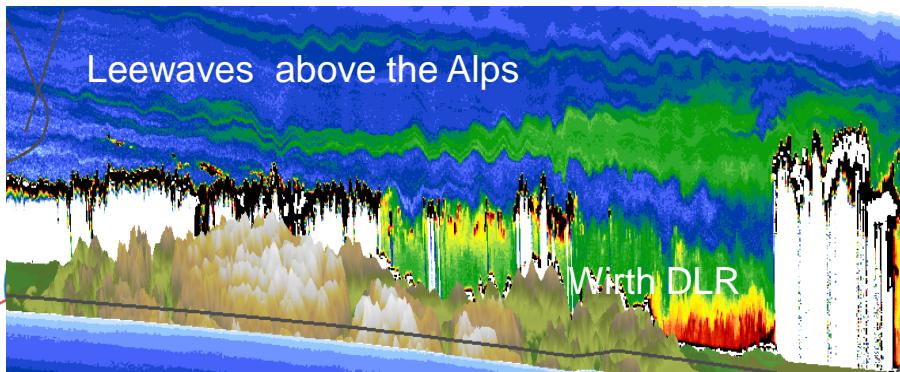


ML-CIRRUS Flight Overview

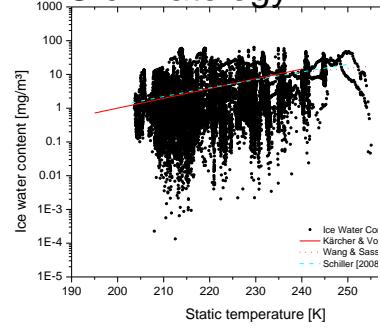
	Date	Mission Scope	Region	Intercomparison	Remarks	Flight duration
Mission 4	2014-03-26	Contrail Cirrus, Northern Atlantic Flight Corridor	Great Britain, Atlantic			8:30
Mission 5	2014-03-27	WCB Inflow and Outflow	Alps, Italy, Austria, Germany			4:45
	2014-03-28					
Mission 6	2014-03-29	Leewave Cirrus, Cirrus with high updraft velocity, WCB	France, Pyrenees, Spain		Influenced by Sahara dust	7:30
	2014-03-30					
	2014-03-31					
Mission 7	2014-04-01	Contrail Cirrus, HALO	Germany	MIM, Leipzig Lidar, Radio Sonde DWD	Influenced by Sahara dust	06:35
	2014-04-02					
Mission 8	2014-04-03	WCB Outflow with Sahara dust	Germany		Influenced by Sahara dust	05:15
Mission 9,10	2014-04-04	Clean Jet Stream Cirrus, low updraft, (un)polluted WCB	Spain and Portugal	CALIPSO overpass	Partially infl. by Sahara dust	09:55
	2014-04-05					
	2014-04-06					
Mission 11	2014-04-07	Contrail cirrus, HALO	Germany	MIM, Leipzig Lidar, RS & Hygrometer DWD	Partially infl. by Sahara dust	5:35
	2014-04-08					
	2014-04-09					
Mission 12	2014-04-10	Contrails and Cirrus	Germany, TRA Pfalz	Contrail Probing	Partially infl. by Sahara dust	3:15
Mission 13,14	2014-04-11	Huge WCB and Outflow	Great Britain	Lagrangian approach		10:00
	2014-04-12					
Mission 15	2014-04-13	Cold Cirrus in high pressure system, Jet Stream Cirrus	Spain and Portugal	Many Contrails		7:15
	2014-04-14					
Mission 16	2014-04-15	Föhn, divergence, waves	Alps	Test: Liquid Cloud, Aerosol Inlet		3:00
Sum						88:10

New CIRRUS Results

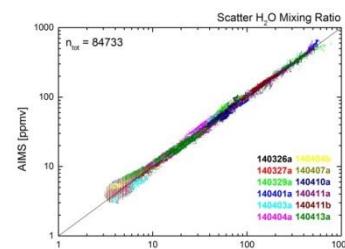
- Climatologies of properties of mid-latitude cirrus clouds (IWC, D, n_{ice} , n_{aero} , Ext, RHI)
- Progress in water vapor observations
- Cirrus statistics in different meteorological regimes (frontal cirrus, leewave cirrus, ...)
- Chain Forecast- LIDAR/in-situ observation, analysis, model improvement



IWC climatology



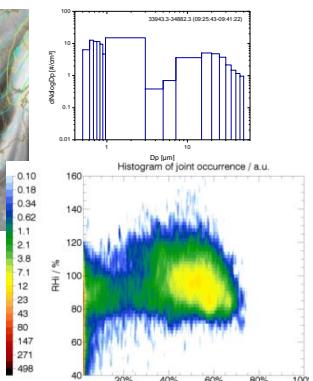
H₂O intercomparison



Kaufmann DLR



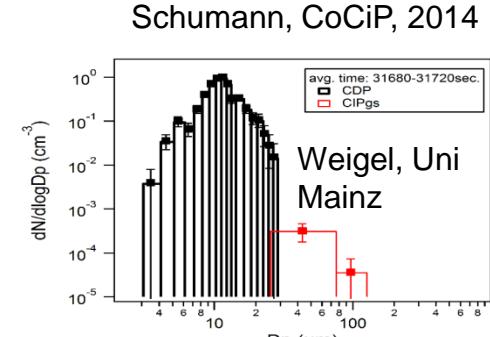
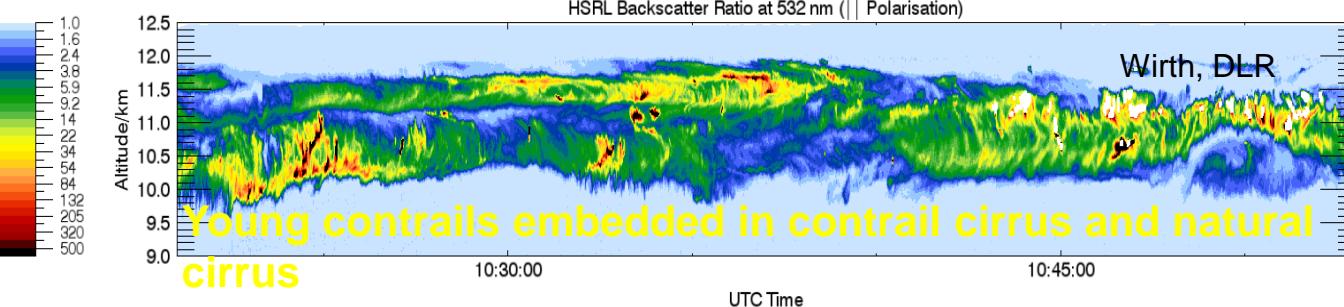
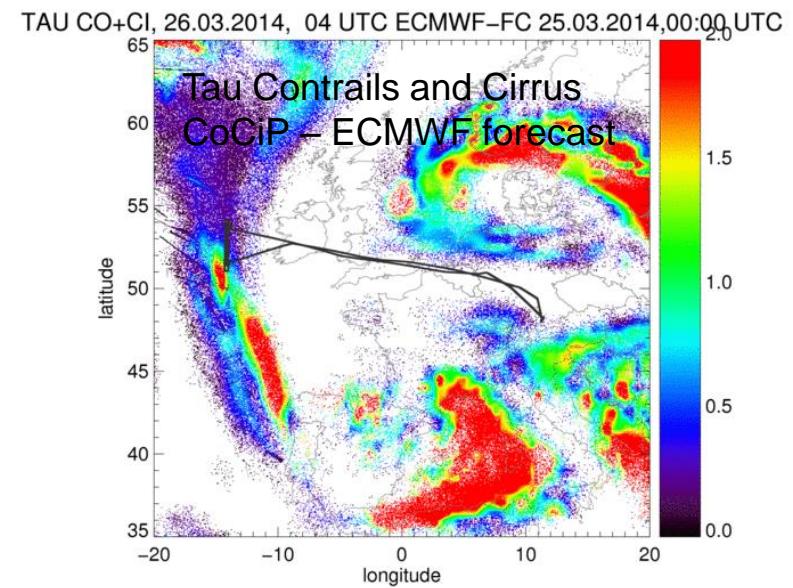
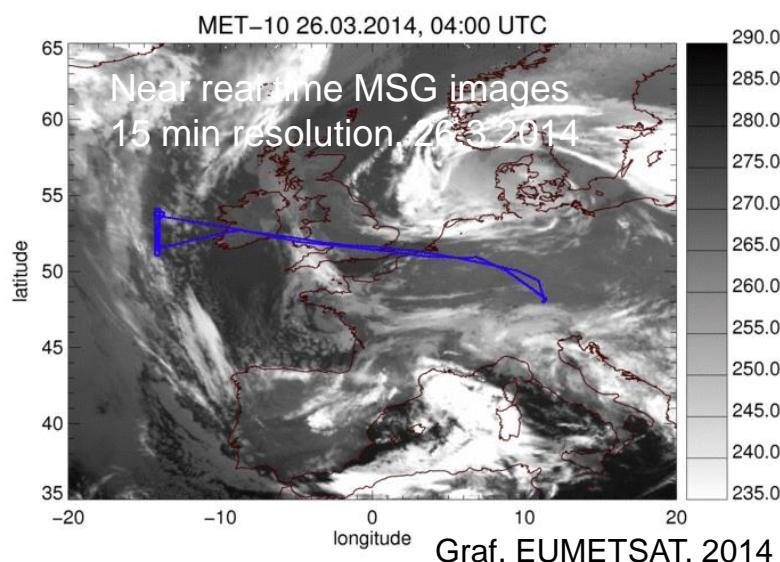
Forecast and detection
of frontal cirrus



Wirth DLR

Results on contrail cirrus

- Evaluation of contrail cirrus predictions
- New in-situ observations in contrail cirrus (contrail cirrus outbreak above Eastern Atlantic)
- Study on a „pure“ contrail cirrus case
- Intercomparison of contrail cirrus models with LIDAR/in-situ/satellite observations

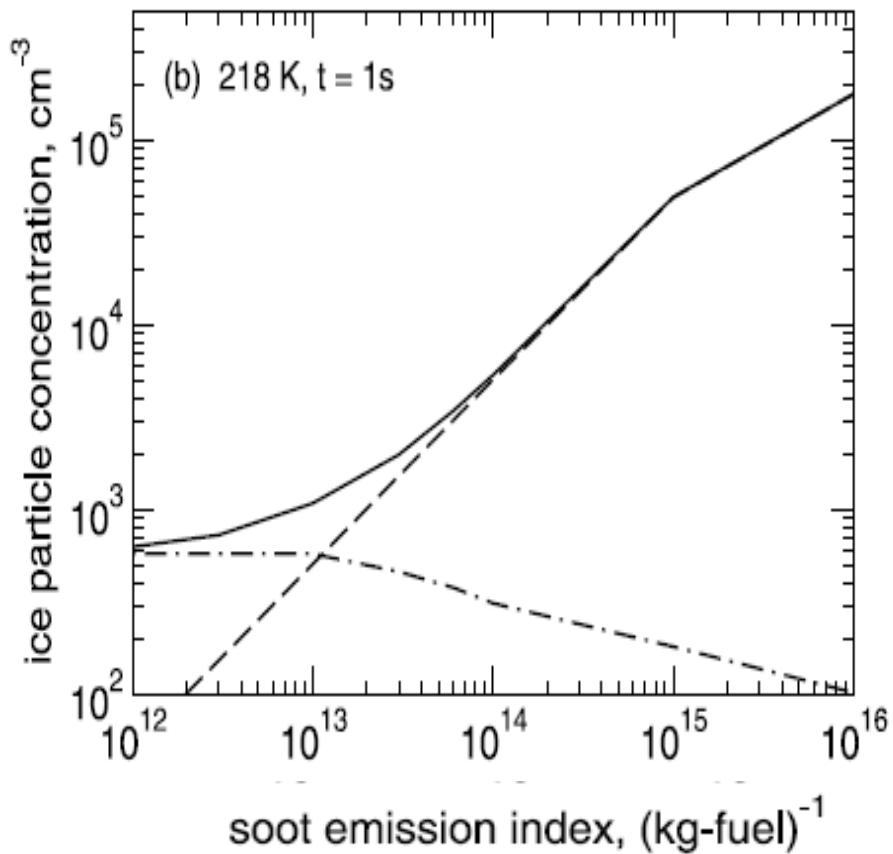
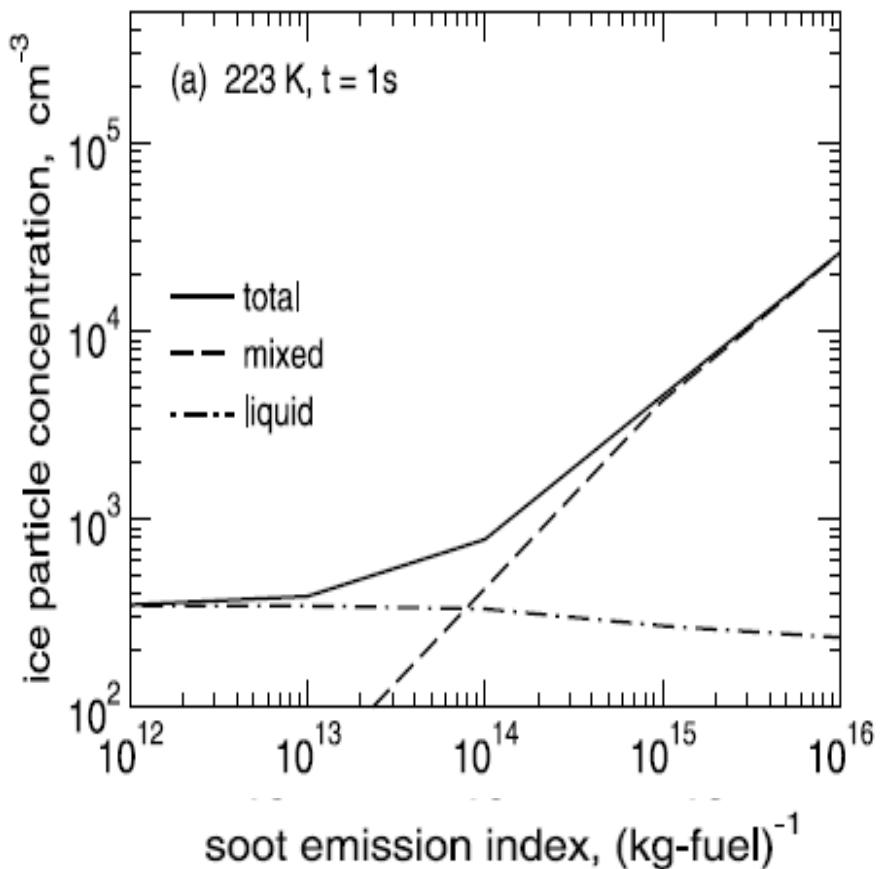




Thank you



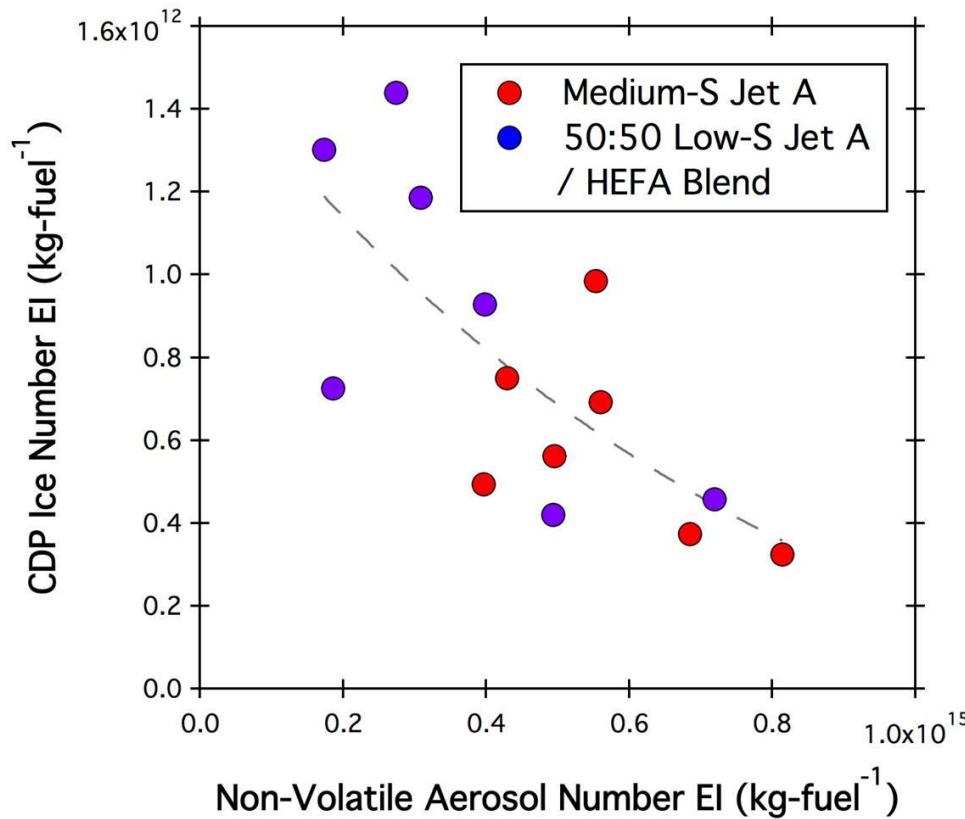
Ice number density versus EI_{non vol}



Preliminary data



Increase in EI_{nonvol} shifts ice distribution to smaller sizes



- CDP measures particles from 2 to 50 μm
- Indications for a small shift of the size distribution to smaller particle sizes with increasing ice number density

